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An approach to energy savings and improved environmental impact through restructuring Jordan's transport sector

A. Al-Ghandoor *

The Hashemite University, Zarqa, Jordan

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ABSTRACT

This paper illustrates a new approach to forecast the potential energy savings and environmental impact of adopting energy efficient practices in the Jordanian transportation sector. This approach is based on Adaptive Neuro-Fuzzy Inference System (ANFIS) and the double exponential smoothing techniques. The ANFIS model has been developed using socio-economic and transport related indicators based on annual number of vehicles, vehicle owner level, income level, and fuel prices in Jordan. The double exponential smoothing technique has been used to forecast the different transport indicators to feed the developed ANFIS model in order to forecast the transport energy demand for the next two decades. The model has been validated using testing data and has showed very accurate results of 97%. The results show that the transport energy demand is expected to increase at % 4.9 yr^{-1} from years 2011–2030. As an example of the energy efficiency improvement in the transportation sector, this paper examines potential benefits that can be achieved through the introduction of diesel cars to the passenger cars market in Jordan. Five scenarios are suggested for implementation and investigated using the new approach on the basis of local and global trends over the period 2011–2030. It is demonstrated that introducing diesel passenger cars can slow down the growth of energy consumption in the transportation sector resulting in significant savings in the national fuel bill. It is also shown that this is an effective and feasible option for cutting down CO_2 emissions.

Contents

* Tel.: +962 796 535999.
E-mail address: gandoor2002@yahoo.com

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1. Introduction

All researchers, experts and even politicians have considered that the world's transportation system is not sustainable because the automobile use and density have strongly increased during the last few decades [1]. Transportation systems not only play a major role in the sustainability of the earth but also they, themselves, must be sustained in order to continue to afford to all people access to the economic and social opportunities necessary for meaningful life, i.e. high demand and security of supply as well as urban pollution issues. Thus, most of the recent studies are concentrated on the area of increasing energy efficiency by better management, operation, energy sources, and transport technologies, etc.

Globally, the final energy consumption was growing from 4676 million tons of oil equivalent (Mtoe) since 1973 to 8429 Mtoe in 2008 [2]; transportation sector share increased from 23.1% in 1973 to 27.3% of the total global energy consumption in 2008. This is mainly due to the continuing growth in household incomes and number of vehicles [3]. On the other hand, global CO_2 emissions increased from 21 billion tons in 1990 to 29.4 billion tons of CO_2 in 2008; transportation sector contributed 6.6 billion tons of CO_2 which is 22.5% of total CO_2 emissions in 2008 [4].

Unfortunately, unlike other Arab neighboring countries, Jordan is a non-oil producing country with limited natural resources and minerals. As other developing Asian countries, it has a rapid population growth of about 2.2% [5]. The population and economic growth as well as development that Jordan experienced since its independence, in mid 1950s, implied a gradual shift of the population from rural to urban areas. Thus, urban population has increased from about 70% in 1990, to 82% in 2010, of total population, putting the kingdom among the most urbanized countries in Asia. A major structural phenomenon of urbanization is the increasing shift of large proportions of the population to modern centers with relatively high incomes, requiring higher rates of energy consumption to sustain the new life.

In recent years, concern about energy consumption in Jordan has been growing, especially, in the transport sector which was probably affected the most by the economic and technological changes that the country has witnessed during the past three decades. For example, the number of road vehicles in Jordan rose by almost 1000% during the last 30 years, while the number of air passengers increased approximately by 460% [6]. The enormous increase in the number of operating vehicles has contributed to a significant increase in the local energy demand and an increasing amount of damage to the natural environment as a result of polluting emissions. This is ensuing principally in the Amman-Zarqa region, in the middle of the kingdom, where about 60% of the national population and nearly 70% of the urban populations live [7].

In this study, a new approach to model and forecast energy consumption in the Jordanian transportation sector will be developed. This approach is based on Adaptive Nuero-Fuzzy Inference System (ANFIS) and double exponential smoothing techniques. The ANFIS model will explain the main driving forces behind fuel consumptions change, for the transportation sector, since energy planning is not possible without a deep knowledge and analysis of past and present consumption; this will form the first objective of this study. The second objective is to forecast the transport energy demand for the next two decades using the double exponential smoothing technique to forecast the different transport related indicators that are necessary to feed the developed ANFIS model. The third objective is to evaluate the impacts of introducing diesel cars measure on future energy consumptions and associated reduction in CO_2 emissions using the new approach developed in this paper. Such studies would help energy policy planners in understanding the implications of changes in the exogenous variables when the underlying relationships are fairly stable and will be helpful in developing highly applicable and productive planning for future transport energy policies. It is worth mentioning here that this paper is among a series of papers published by same author to identify the opportunities of energy savings in different Jordanian sectors [8,9].

2. Energy and environment in Jordan

In Jordan, crude oil has principally dominated the Jordanian energy sector for the last four decades and it has been the chief primary energy source for economic and social developments. Recently, the imported natural gas (NG), from Egypt is used to substitute the heavy fuel oil (HFO) and diesel fuel in main power plants. Table 1 shows fossil fuels consumption during 2009 [10]. In terms of energy equivalent value, HFO, diesel, gasoline, and NG represent more than 89% of all types of fuel consumed in Jordan.

According to the ministry of environment and mineral resources (MEMR), in 2009, electricity and final energy consumptions reached nearly 11,956 GWh and 5021 t oil equivalent (toe) respectively; of these the transportation sector had share equal to 39% of the total final energy consumptions. Figs. 1 and 2 show the percentage share of sectoral final energy and electricity consumptions in 2009 [10].

In addition to energy use, the associated greenhouse gas emission and their potential effects on the global climate change are nowadays a worldwide concern. The recognition of the danger posed by continued emission accumulation of greenhouse gases (GHG) into the atmosphere has led to the Rio and Kyoto summits on climate change in 1992 and 1997, respectively, and the UN framework convention on climate change. CO_2 is the most important GHG, and most of its emission come from combustion of fossil fuels in all sectors of the economy, i.e. energy supply chain and final users. Jordan has signed and adopted almost all the international and regional conventions relating to environmental protections.

Table 1
Fossil-fuels consumption in Jordan during 2009.

Fuel type	Consumption (10^3 t)[a]	Energy equivalent (10^3 toe)	Percentage of total (%)
LPG	339	379.8	4.7
Gasoline	1022	1,064.5	13.1
Jet fuel	318	331.1	4.1
Kerosene	111	114.7	1.4
Diesel fuel	1,614	1643.8	20.2
Heavy fuel oil	823	746.3	9.2
Natural gas	3086×106 Nm^3	3,849.6	47.3
Total	–	8,129.8	100

[a] Except where shown.

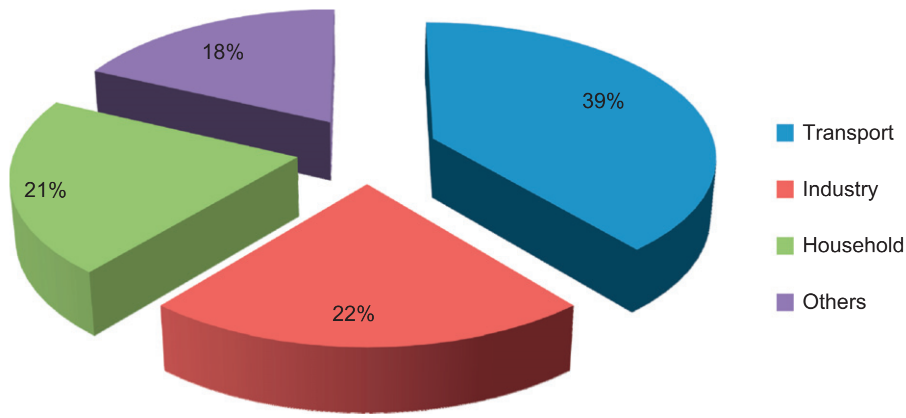

Fig. 1. The percentage share of sectoral consumption of final energy in Jordan for 2009.

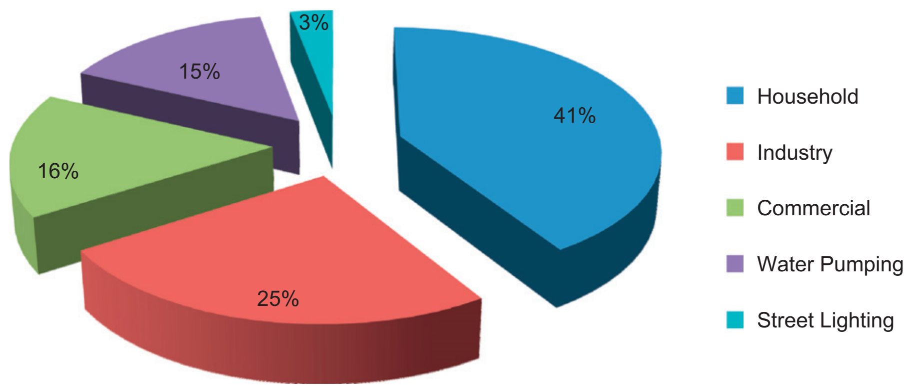

Fig. 2. The percentage share of sectoral consumption of electricity in Jordan for 2009.

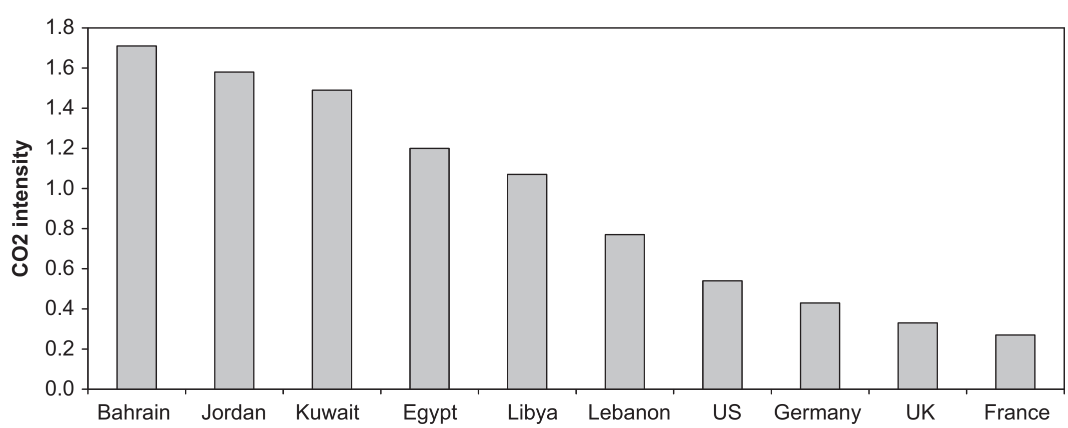

Fig. 3. CO_2 emission intensity in selected Middle Eastern and OECD countries (kg CO_2/2000 US$).

Among these are the Biological Diversity and Climate Change Convention, which were approved during the Earth Summit in Rio de Janeiro in 1992. Jordan's annual CO_2 emissions were estimated in 2004 to be 16.70×10^6 t [11]. Although this constitutes less than 0.1% of the world's annual CO_2 emissions, its intensity is considerably high: about four times that of most Western European countries, and almost similar to those of oil producing Arab countries as indicated in Fig. 3 [8]. This implies that there is room for energy efficiency improvement and emission reduction in all sectors. Jordan's CO_2 emissions are mainly attributed to three sectors: energy production, industry and transportation where they are responsible for 39%, 25%, and 21% of the national CO_2 emissions, respectively. The share of the transportation sector is equivalent to 3.51×10^6 tones/year.

3. Overview of Jordan's transportation sector

Jordan's transportation sector is dominated by road transportation since there are no rail networks and marine transportation is negligible due to the geographical location of the country. The national network of roads extends to cover 7891 km, 3249 km of which are main roads, while the remaining are either side or rural roads [12]. In 2009, the total number of registered vehicles was nearly 995 thousand vehicles, with passenger cars taking a share of around 65% of this number[1]. A breakdown of vehicles in Jordan

[1] All figures and statistics on vehicle numbers, classifications, and registrations were calculated using the comprehensive data obtained from the

Table 2
Breakdown of 2009 total registered vehicles in Jordan according to vehicle type.

Vehicle type	Number	Percentage
Passenger car	643,605	64.7
Minibus	18,900	1.9
Bus	3979	0.4
Van/pickup	103,454	10.4
Freight/truck	173,087	17.5
Motorcycle	3979	0.4
Other	47,749	4.8
Total	994,753	100.0

according to vehicle type is presented in Table 2. Private vehicles represent 82.8% of the total stock of registered vehicles, while public vehicles represent 8.4%, and the remaining 8.8% are registered as government, agricultural, tourist, or special purpose vehicles.

Fig. 4 shows the development of fuel consumption during 1985–2009 [13]. It can be seen that the consumption increased from only 972×10^3 toe in 1985 to 1952×10^3 toe in 2009 corresponding to an average annual growth rate of 4.3%. This consumption trend can be attributed to a group of inter-related factors: number of registered vehicles, vehicle ownership level (cars/person), income level (gross domestic product per capita, $/capita), and local fuel prices, in addition to external economic and socio-political factors.

3.1. Number of registered vehicles (V)

The number of registered vehicles is taken as an indicator for the amount of vehicle activity since more the number of vehicles registered, higher the amount of vehicle activity. This factor is supposed to be the most strongly influencing factors for transport energy consumption.

3.2. Vehicle ownership level (OL)

People in Jordan have progressively changed their travel behavior by relying more on private vehicles, and using them more frequently than ever before which led to an increase on the vehicle ownership level. This is expected to cause an increase in the amount of fuel consumption.

3.3. Income level (IL)

As the income level increases, living standard would rise, and people are able to afford a vehicle or additional vehicle for the convenience of themselves and their family member, in order to access various places at any time, instead of taking public transport, and consequently, travel demand increases and transport energy demand increases. In this study, the GDP per capita is taken as a variable indicating the income level. As per capita income level increases, it is expected to see higher vehicle saturation rates and higher rates of utilization.

3.4. Fuel price ($F)

It is expected that when unit price of fuel increases, people will respond by reducing their consumption of fuel or switching to small engine sizes as a substitute to large engine sizes. In this study, the weighted average prices of different transport fuel prices are taken as a variable.

(*footnote continued*)
Department of Drivers and Vehicles Licensing database through personal efforts and communications.

4. Data sources

Historical data, during the studied period of 1985–2009 from the related government agencies were utilized to develop the ANFIS model of energy consumptions of the Jordanian transportation sector. The focus on this time frame largely reflects the availability of data as required for the purposes of this study. Fuel consumptions and fuel retail prices were obtained from the Ministry of Energy and Mineral Resources [13]. The Gross Domestic Product (GDP) values were obtained from the Central Bank of Jordan [14]. Population values were taken from the Department of Statistics [5]. The information related to registered vehicles in Jordan was obtained by compiling the raw-comprehensive data obtained from the Department of Drivers and Vehicles Licensing through personal effort and communication [15]. It is worth mentioning here that the data developed and analyzed in this study is not available at both researchers' as well governmental levels. Table 3 summarizes the complete set of data used in building the ANFIS model.

5. Methodology

Depending on the available data, several models have been proposed to model transport energy consumption that can be classified into two groups: econometric and artificial intelligence approaches. The first group includes multiple linear regression [16], partial least square regression [17], and time series [18] while the second group includes artificial neural network [19], harmony search algorithm [20] and Fuzzy theory [21]. The regression analysis is a statistical technique that involves exploring the relationships between two or more variables through building a model-equation that relates the response, i.e. variable of interest, to a set of predictor variables. Time series models are the most simplest of models which uses time series trend analysis for extrapolating the future energy requirement. In the Fuzzy system, data are represented, closer to human-like thinking, using fuzzy rules instead of exact rules. A literature for different approaches can be found in [22].

In this paper, a new methodology that combines the two approaches is suggested and as follows:

Step 1: Develop a model for the Jordanian transport energy demand based on historical variables data using ANFIS.
Step 2: Use the time series forecasting technique to forecast each variable during the future study period.
Step 3: Use the data obtained from Step 2 in the ANFIS model developed in Step 1 to forecast Jordan transport energy demand.
Step 4: Implement the energy efficient measure into the model developed in the previous steps.

5.1. Adaptive nuero-fuzzy inference system (ANFIS)

A fuzzy inference system can be considered to be composed of five functional blocks described as follows:

1) A rule base containing the fuzzy if-then rules.
2) A database which defines the membership functions of the fuzzy sets used in the fuzzy rules.
3) A decision-making unit which performs the inference operations on the rules.

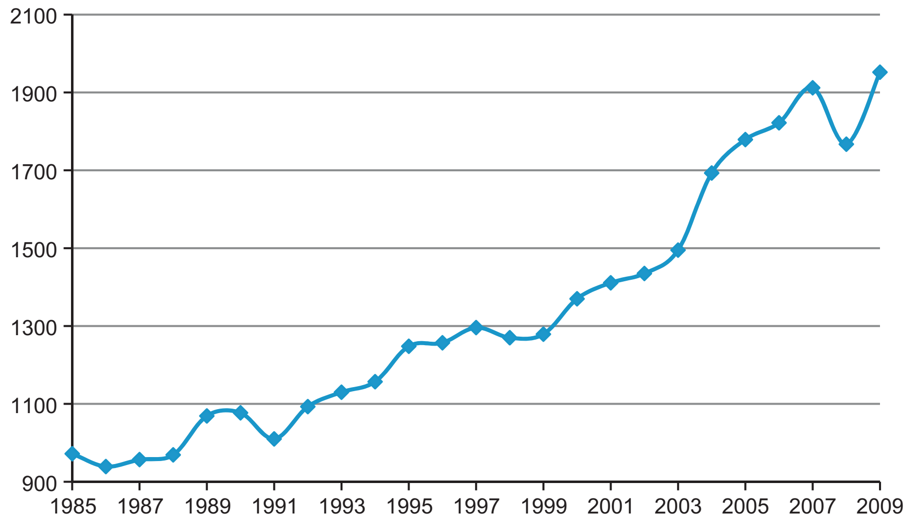

Fig. 4. Development of transport energy consumption (1000 toe) over the period of 1985–2009.

Table 3
Data set for the transportation sector ANFIS model.

Year	Energy (1000 toe)	Number of vehicle (*V*)	*IL* ($/capita)	*OL* (car/person)	*$F* ($/L)
1985	972	161,168	2334	0.060	0.310
1986	939	171,616	2542	0.061	0.310
1987	957	181,101	2466	0.062	0.310
1988	969	191663	2248	0.063	0.310
1989	1069	194,641	1703	0.062	0.346
1990	1077	197,186	1499	0.057	0.346
1991	1010	202,327	1410	0.055	0.346
1992	1093	228,047	1631	0.059	0.367
1993	1130	246,038	1658	0.062	0.367
1994	1157	259,459	1740	0.063	0.367
1995	1248	275,654	1805	0.065	0.367
1996	1257	298,249	1720	0.068	0.367
1997	1296	330,573	1724	0.073	0.367
1998	1270	359,154	1794	0.078	0.367
1999	1279	393,729	1792	0.083	0.397
2000	1370	452,308	1834	0.093	0.397
2001	1411	498,676	1834	0.100	0.456
2002	1435	534,465	1880	0.105	0.456
2003	1495	567,459	1918	0.109	0.494
2004	1693	616,361	2030	0.115	0.540
2005	1779	684,285	2119	0.125	0.611
2006	1822	764,518	2178	0.137	0.731
2007	1912	841,933	2408	0.147	0.731
2008	1767	905,592	2445	0.155	0.950
2009	1952	994,753	2750	0.166	0.640

4) A fuzzification interface which transforms the numerical input variables into fuzzy variables with linguistic labels.
5) A defuzzification interface which transforms the fuzzy results of the knowledge base in combination with the results of the decision-making unit into a numerical output variables.

Energy consumption prediction process is highly variable, nonlinear and complex process. In fact, the energy consumption could be nicely modeled as fuzzy properties. Fuzzy logic can model nonlinear functions of arbitrary complexity. It provides an alternative solution to nonlinear modeling because it is closer to the real world. Nonlinearity and complexity is handled by rules, membership functions, and the inference process which results in an improved performance, simpler implementation, and reduced design costs.

One approach to the derivation of a fuzzy rule base is to use the self learning features of artificial neural networks to define the membership function based on input–output data. A fuzzy inference system (consisting of rules, fuzzy set membership functions, and the defuzzification strategy) are mapped onto a neural network-like architecture.

Adaptive neuro-fuzzy inference system (ANFIS) is a fuzzy inference system implemented in the framework of an adaptive neural network. By using a hybrid learning procedure, ANFIS can construct an input–output mapping based on both human-knowledge as fuzzy If-Then rules and stipulated input–output data pairs for neural networks training. ANFIS architecture is shown in Fig. 5, where x and y are the inputs, f is the output, A_i and $A_n{}^2$ are the input membership functions, w_i and $w_n{}^2$ are the rules firing strengths. Five network layers are used by ANFIS to perform the following fuzzy inference steps: (i) input fuzzification, (ii) fuzzy set database construction, (iii) fuzzy rule base construction, (iv) decision making, and (v) output defuzzification. This is a multi-layered neural network architecture where the first layer represents the antecedent fuzzy sets, while the consequent fuzzy sets are represented by the middle layers, and the defuzzification strategy by the output layer. The nodes which have 'square' shape are those containing adaptable parameters, whereas the 'circular' nodes are those with fixed parameters.

ANFIS is more powerful than the simple fuzzy logic algorithm and neural networks, since it provides a method for fuzzy modeling to learn information about the data set, in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data [23].

ANFIS modeling and prediction of transport energy demand starts by obtaining a data set (input–output data points as given in Table 3) and dividing it into training and validating data sets. Each input/output pair contains four inputs (i.e., annual number of vehicles (V), vehicle ownership level (OL), income level (IL), and fuel prices (F) and one output (i.e., energy consumption (E) in tons of oil equivalent (toe)). The training data set is used to find the initial premise parameters for the membership functions by equally spacing each of the membership functions. A threshold value for error between the actual and desired output is determined. The consequent parameters are computed using the least squares method. Then, an error for each data pairs is found. If this error is larger than the threshold value, the premise parameters are updated using the back propagation neural networks. This

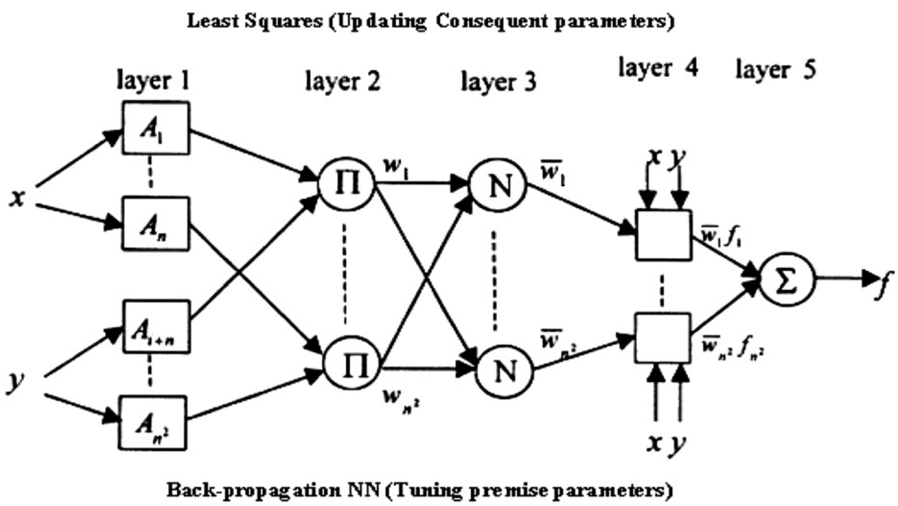

Fig. 5. ANFIS Architecture [23].

process is terminated when the error becomes less than the threshold value. Then, the testing data points are used to compare the model with actual system for validating purposes.

The overall energy consumption output (*f*) of ANFIS given in Fig. 5, can be written as

$$E=(\overline{w_1}(V))P_1^1+(\overline{w_1}(OL)P_2^1+(\overline{w_1}(IL)P_3^1+\left(\overline{w_1}(\$F)P_4^1\right.$$
$$+(\overline{w_1})P_0^1+\ldots+(\overline{w_{n^2}})P_0^{n^2} \tag{1}$$

The full equation has ($5n^2$) terms, where n^2 is the number of input implications. In this model, of Eq. (1), (*V*, *OL*, *IL*, *and* $F) are the input parameters (i.e., annual number of vehicles, vehicle owner level, cars/person, income level, \$/capita, and fuel prices, \$/liter), and $\overline{w_1}$ to $\overline{w_{n^2}}$ are the normalized firing strengths of fuzzy rules. The consequent parameters of the fuzzy membership functions ($P_1^1,\ldots,P_o^{n2}$), are tuned off-line using linear least square method, and then updated on-line by a gradient descent back-propagation neural networks.

5.2. Time series analysis

In order to use the developed ANFIS model to forecast transport energy demand, it is necessary to have forecasted values for each predictive variable. For this study, projected values for each predictor were determined using a forecasting tool based on time series technique with double exponential smoothing since the historical data of number of vehicles, ownership level, income level, and fuel price over the period 1985–2009 shows an evident long-run trend. The double exponential smoothing forecasting time series method is recommended in such situations [24]. The double exponential forecasting equation is as follows:

$$F_{t+m}=a_t+b_t m \tag{2}$$

where F_{t+m} is the forecast after *m* the number of periods ahead to be forecast, a_t the forecasted intercept, and b_t the forecasted slope. The intercept a_t and the slope b_t are estimated as follows:

$$a_t=2S_t'-S_t'' \tag{3}$$

$$b_t=\frac{\alpha}{1-\alpha}(S_t'-S_t'') \tag{4}$$

$$0\le\alpha<1 \tag{5}$$

where α is the smoothing constant used to weight current and past observations, and S_t' and S_t'' are the single and double exponential smoothing values for time *t*. These S_t' and S_t'' values are calculated as follows:

$$S_t'=\alpha X_t+(1-\alpha)S_{t-1}' \tag{6}$$

$$S_t''=\alpha S_t'+(1-\alpha)S_{t-1}'' \tag{7}$$

The higher α means more weight is given to the most recent observations. Before running the analysis, α should be selected. The forecasts are calculated using different α's, and the α that gives a small mean square error for the forecasts and shows an expected future growth is chosen. In addition to choosing appropriate α, values of S_{t-1}' and S_{t-1}'' must be assumed when $t=1$ since no such values exist for this period. This problem can be solved by assuming that both values are equal to the initial historical values [24].

5.3. Evaluating savings from introducing diesel cars measure into Jordanian transportation market

In the transportation sector, efficiency measures to improve fuel economy and reduce CO_2 emission of vehicles have proven to the most effective tools in controlling oil demand and greenhouse gas (GHG) emissions in many regions and countries around the world. Several countries have implemented fuel economy and greenhouse gas (GHG) emission standards such as USA, European Union, Canada, Japan, China, Taiwan, South Korea and Australia [25,26]. In the United States, Canada, UK, Netherlands, a fuel economy label, which is published annually by the Department of Energy, must be affixed to the window of all new vehicles. This label contains information for fuel economy label which gives consumers an idea of the fuel economy for a specific model to compare with other cars [27]. The EU has a target of 46 mpg by 2012 which would be met through an "integrated approach" between the EU and the association of car manufacturers. The long-term goal for the fleet average of new cars is 58 mpg by 2020 with a review in 2013 [28]. Recently, China has adopted new standard of fuel economy for its passenger vehicle fleet to control the country's rapidly growing vehicle market. In this standard, a maximum allowable fuel consumption limits by weight category is set and classified into 16 weight classes, ranging from vehicles weighing less than 750 kg to vehicles weighing more than 2500 kg [29].

In Jordan, there are no such standards or regulations that control the vehicle market. In addition and since late sixties, it is not permitted to register and/or operate passenger cars powered by compression ignition (C.I) engines using diesel fuel for both of private and public use. Thus, all saloon cars are run by spark ignition (S.I) engines, consuming gasoline. The clear fuel economy

and emission advantage that diesel passenger cars have over their gasoline counterparts can be one of the answers offered to alleviate the worsening energy crisis in Jordan on one hand and to improve the CO_2 emission intensity.

From a thermodynamic point of view, diesel engine is an efficient reciprocating prime mover due to the relatively high compression ratio that can be considered and used in designing such engines [30,31].

Due to the lack of policy models that are able to capture the full effects of adopting energy efficient measures, this study uses the scenario approach for this analysis. Scenarios are tools for ordering one's perception about alternative future options, and the end result might not be an accurate picture of tomorrow but can give better decisions about the future. No matter how things might actually turn out, both the analyst and the policy maker will have a scenario that resembles a given future, and that will help us to think about both the opportunities and the consequences of that future. In this study, five different scenarios are suggested:

- Scenario A: The situation will remain unchanged during the study period.
- Scenario B: Diesel passenger cars will take a yearly constant share of 20% of the new cars from 2011 until 2030.
- Scenario C: Diesel passenger cars will take a yearly constant share of 60% of the new cars from 2011 until 2030.
- Scenario D: Diesel passenger cars will linearly increase to 20% of the new cars from 2011 until 2030.
- Scenario E: Diesel passenger cars will linearly increase to 60% of the new cars from 2011 until 2030.

The suggested shares for scenario B and C are justified by the popularity diesel cars are currently enjoying in Europe along with the relatively high fuel prices in comparison to local income levels in Jordan. Scenarios D and E assume a more gradual and conservative approach in introducing diesel cars to the Jordanian market.

In order to quantify the fuel economy advantage of diesel engines, a comparative survey was carried out between diesel and gasoline powered passenger cars covering seven different models with engine displacements ranging from 1.3 to 2.0 L. This survey was based on published manufacturer's data of fuel consumption under urban and extra-urban driving conditions. The results of this survey show that, on basis of litres/100 km, for diesel cars it is 20–30% which is lesser than comparable gasoline cars. Similar results have also been reported by other studies and surveys [32,33]. For all five scenarios diesel passenger cars will be assumed to have an average 20% advantage on fuel economy and CO_2 emissions in comparison with comparable gasoline passenger cars.

To evaluate the potential savings at period t (ES_t) for scenarios B and C, the following model is developed and employed in this investigation:

$$(ES)_t = SF \times MS \times CP \times \left[\left(\frac{E_0 \times t}{T}\right) + (E_t - E_0)\right], \tag{8}$$

In Eq. (8), SF represents the saving factor resulting from introducing the diesel passenger cars, MS proposed market share of the diesel passenger cars measure, CP the coverage percentage of passenger cars within the transportation sector (60%) (MEMR, 2010), E_0 fuel consumption of the transportation sector at base year 0 (2010 in this study), E_t predicted fuel consumption of the transportation sector for year t, and T study period length (twenty years from 2011 to 2030).

Eq. (8) can be rewritten as

$$\begin{aligned}(ES)_t = SF \times CP \times \Big[& MS\left(\tfrac{E_0}{T}\right)_1 + \ldots + MS\left(\tfrac{E_0}{T}\right)_t + MS(E_t - E_{t-1}) \\ & + MS(E_{t-1} - E_{t-2}) \ldots + MS(E_1 - E_0)\Big]\end{aligned} \tag{9}$$

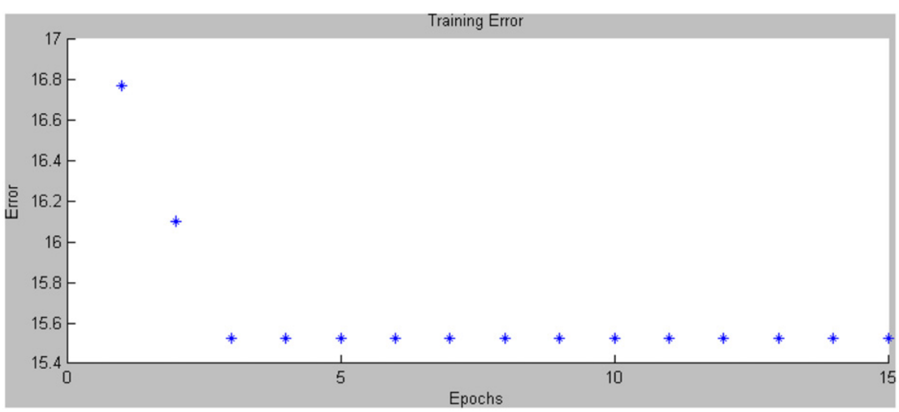

Fig. 6. ANFIS training curve.

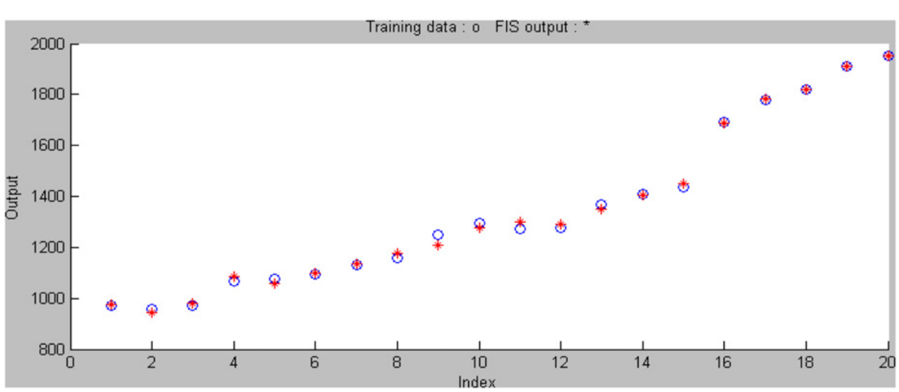

Fig. 7. Actual and predicted transport energy demand values.

or,

$$(ES)_t = SF \times CP \times \left[\sum_{i=1}^{t} MS\left(\frac{E_0}{T}\right)_i + \sum_{i=1}^{t} MS(E_i - E_{i-1}). \right] \quad (10)$$

However, this model assumes that both the uniform converted portion of the base fuel consumption as well as the increase in fuel consumption over the base year of the Jordanian transportation sector would be at assumed market share (scenarios B and C). However, to be conservative, scenarios D and E assume the market share to be taken place progressively during the study period. Hence, the model becomes

$$(ES)_t = SF \times CP \times \left[\sum_{i=1}^{t} \left(\left(\frac{i}{T}\right) MS\left(\frac{E_0}{T}\right) \right) + \sum_{i=1}^{t} \left(\left(\frac{i}{T}\right) MS(E_i - E_{i-1}) \right) \right] \quad (11)$$

where $1 \le t \le T$.

6. Results and discussions

6.1. A fuzzy-based model for transport energy demand prediction

The fuzzy logic toolbox of Matlab 7 was used to obtain the ANFIS model. A total of 55 nodes and 16 fuzzy rules were used to build the fuzzy systems for modeling the energy consumption (Eq. (1)). The neural network training for building a fuzzy model for energy used 20 training data points, and 15 learning epochs. Fig. 6 shows the training curve of ANFIS with root mean square error (RMSE) of 15.5 (i.e., almost 2%). A comparison between the actual and ANFIS predicted energy intensity values after training is shown in Fig. 7, which shows that the system is well-trained to model the actual transport energy demand.

Five points, which are different from the training data, were used to validate the system. These validation data points are given in Table 4. The final ANFIS-predicted energy demand (i.e., the energy model) is shown in Fig. 8 as a surface plot of transport energy consumption (E) as a function of the number of vehicles, ownership level, income level and fuel price.

Table 4
Validation results.

Test point	Actual output	Predicted output	% Error
1	939	946	0.75
2	1010	1070	5.94
3	1257	1230	2.20
4	1495	1520	1.67
5	1767	1850	4.70
Average % error			**3**

Table 5
Smoothing constants (α's) for the different variables.

	V	*OL*	*IL*	*$F*
Smoothing constant (α)	0.99	0.99	0.85	0.28

Table 6
Projected predicted values for the different variables.

Year	Energy (1000 toe)	*V*	*OL* (car/person)	*IL* ($/capita)	*$F* ($/L)
2010	**2130**	1,083,408	0.178	2985	0.824
2011	**2350**	1,172,066	0.189	3226	0.859
2012	**2390**	1260723	0.201	3466	0.894
2013	**2482**	1,349,381	0.212	3707	0.929
2014	**2675**	1,438,039	0.224	3947	0.964
2015	**2630**	1,526,696	0.235	4187	0.999
2016	**2760**	1,615,354	0.247	4428	1.034
2017	**2930**	1,704,011	0.258	4668	1.069
2018	**2870**	1,792,669	0.270	4908	1.104
2019	**2984**	1,881,327	0.281	5149	1.139
2020	**3015**	1,969,984	0.293	5389	1.174
2021	**3165**	2,058,642	0.304	5630	1.209
2022	**3290**	2,147,300	0.315	5870	1.244
2023	**3210**	2,235,957	0.327	6110	1.278
2024	**3240**	2,324,615	0.338	6351	1.313
2025	**3310**	2,413,272	0.350	6591	1.348
2026	**3475**	2,501,930	0.361	6831	1.383
2027	**3820**	2,590,588	0.373	7072	1.418
2028	**4125**	2,679,245	0.384	7312	1.453
2029	**4165**	2,767,903	0.396	7553	1.488
2030	**4335**	2,856,560	0.407	7793	1.523

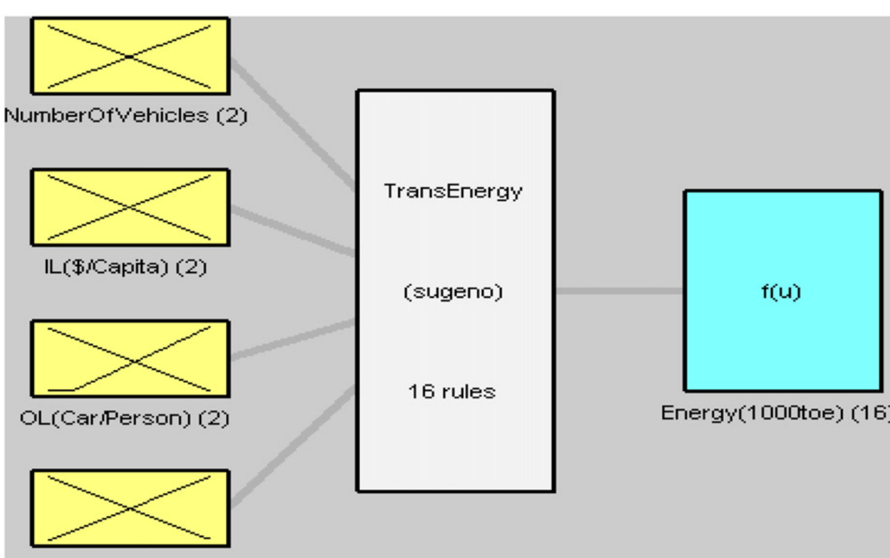

Fig. 8. The final fuzzy-based transport energy prediction system.

Different types of membership functions (MF) of the inputs and output were tested to train the ANFIS prediction system. A two (triangular) type MF for each input resulted in high accurate modeling results and minimum training and validation errors. The final (MF) were tuned and updated by the ANFIS model to achieve a good mapping of the input variables to the transport energy demand output. The shape of MF is considered a key parameter in tuning the ANFIS. The (MF) shape determines the location of MF parameters, and in turn determines the degree of membership for the input values (i.e., fuzzified inputs), and as mentioned previously, the fuzzy rules premise and antecedent parameters are directly affected by the (MF) shape and parameters. Consequently, the effect of changing (MF) shape will propagate to reach all the ANFIS layers, and will have a considerable effect on the final output of the ANFIS network.

6.2. Model validation

The ANFIS prediction model for transport energy demand was validated by selecting a certain number of data points, different from the other 20 points used for ANFIS training. Each validation data point (i.e., *V*, *OL*, *IL*, and $*F*) was fed into the system of Fig. 8, and then the predicted energy demand values were computed and compared to the actual values of energy demand as shown in Table 4. It is clear from this validation table that the ANFIS predicted values are close to the actual ones. The average percent error in the modeling of energy was 3%, achieving a satisfactory accuracy of prediction of 97%.

6.3. Time series analysis

Using the double exponential forecasting model described in Eq. (2), the projected predictor variables of the transport energy demand can be calculated over the period of 2010–2030 using the values of the smoothing constants (α's) shown in Table 5. The projected predicted values for the different predictors are shown in Table 6.

The final fuzzy-based prediction model for the transport energy demand was used to forecast the transport energy demand for the coming twenty years in Jordan using the predicted variables shown in Table 6. The forecasted results are given in Table 6.

6.4. Impacts of introducing diesel passenger cars measure

Potential savings from introducing diesel passenger cars according to scenarios B–E can be calculated using Eqs. (10) and (11) for each year over the 2011–2030. Consequently, fuel consumption can be computed for all scenarios. Fig. 9 shows the projected final energy consumption of the transportation for scenarios A–C. Results for scenarios D and E were not included in the figure to avoid confusion. It can be seen that scenario A (business as usual) will result in an increase of 103.5% in the transportation sector by 2030 to reach around 4335 toe. The growth can be slowed down to 98.6% and 88.9%

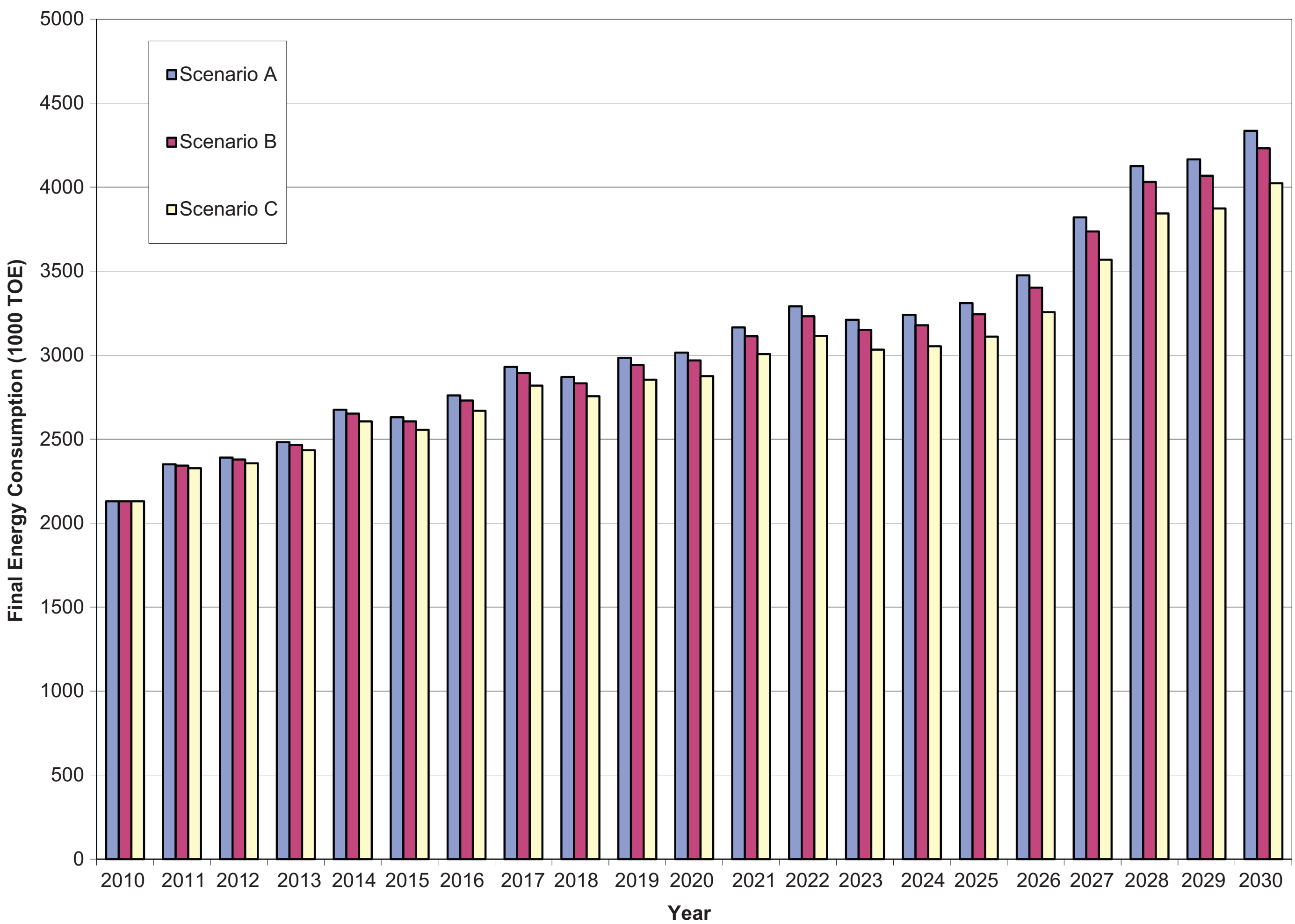

Fig. 9. Projected final energy consumption of the transportation for scenarios A–C.

if scenarios B or C are adopted, respectively. Similarly, scenarios D and E will result in a growth of 99.6% and 91.6%, respectively.

The resulting savings in million US dollars ($) as a result of fuel savings can be calculated following the assumptions listed below:

- Steady prices of crude oil at an average of $100/barrel over the projected period. It is needless to emphasize that prices of crude oil are subject to an array of factors that are extremely difficult to predict. Additional surges in oil prices such as those witnessed over the past few years can significantly increase potential savings.
- The unit price for diesel and gasoline fuels is equal.
- The final efficiency of conversion process from primary to final energy is 72%.

Fig. 10 shows the annual and cumulative savings in the national fuel bill for scenarios B–E. Although the annual savings are limited during the first years of implementation due to the limited penetration of diesel passenger cars, they continue to increase at a steady rate with the increase of the diesel share in the passenger car market to reach $98.9 million in the case of scenario B and $296.6 million in the case of scenario C in 2030. The cumulative resulting savings by 2030 will reach $980 million for scenario B and $2941 million for scenario C. Scenarios D and E represent a slower and more conservative introduction of diesel that will result in slightly reduced annual savings of $80.2 million and $240.9 million and cumulative savings of $539 and $1626 million, respectively.

The projected reduction in CO_2 emissions can also be calculated using the available emission data and assuming a direct relationship between the energy consumption and CO_2 emission. Fig. 11 illustrates these potential reductions on both annual and cumulative basis for scenarios B–E. Scenario B can result in an annual reduction of 216,000 tonnes in 2030 in comparison with scenario A, while scenarios C–E can result in a reduction of 647, 175, and 525 thousands tonnes, respectively, for the same year. The cumulative savings by 2030 will reach 2139 thousands tonnes for scenario B, 6416 thousands tonnes for scenario C, 1177 thousands tonnes for scenario D, and 3547 thousands tonnes for scenario E. As stated in the Clean Development Mechanism (CDM) of Kyoto Protocol, such reduction in carbon emissions can be considered as a source of wealth generation.

The results clearly show that sustainable economic growth should not lead to an increased rate of energy consumption. Thus, energy efficiency should be promoted on the highest decision-making level in order to meet long-term energy demands. In order to do so a comprehensive energy conservation strategy must be developed and enacted as main element in the national energy plan, which must take into account the fuel mix and technologies being employed in various sectors of the economy. Such strategy may include periodic auditing-programs, create incentives to encourage energy conservation, establish an energy-data bank, introduce technical training and public awareness programs and encourage private-sector participation to invest in energy-thrift and efficient-energy programs where their economics are attractive especially in the transportation sector. Several measures could be followed to reduce energy consumption in road transport sub-sector, such as improving mass transport networks, traffic planning and management, car-pooling, improve vehicle maintenance through workshop certification and staff training, introducing diesel powered saloon cars and improve the quality of locally produced fuels.

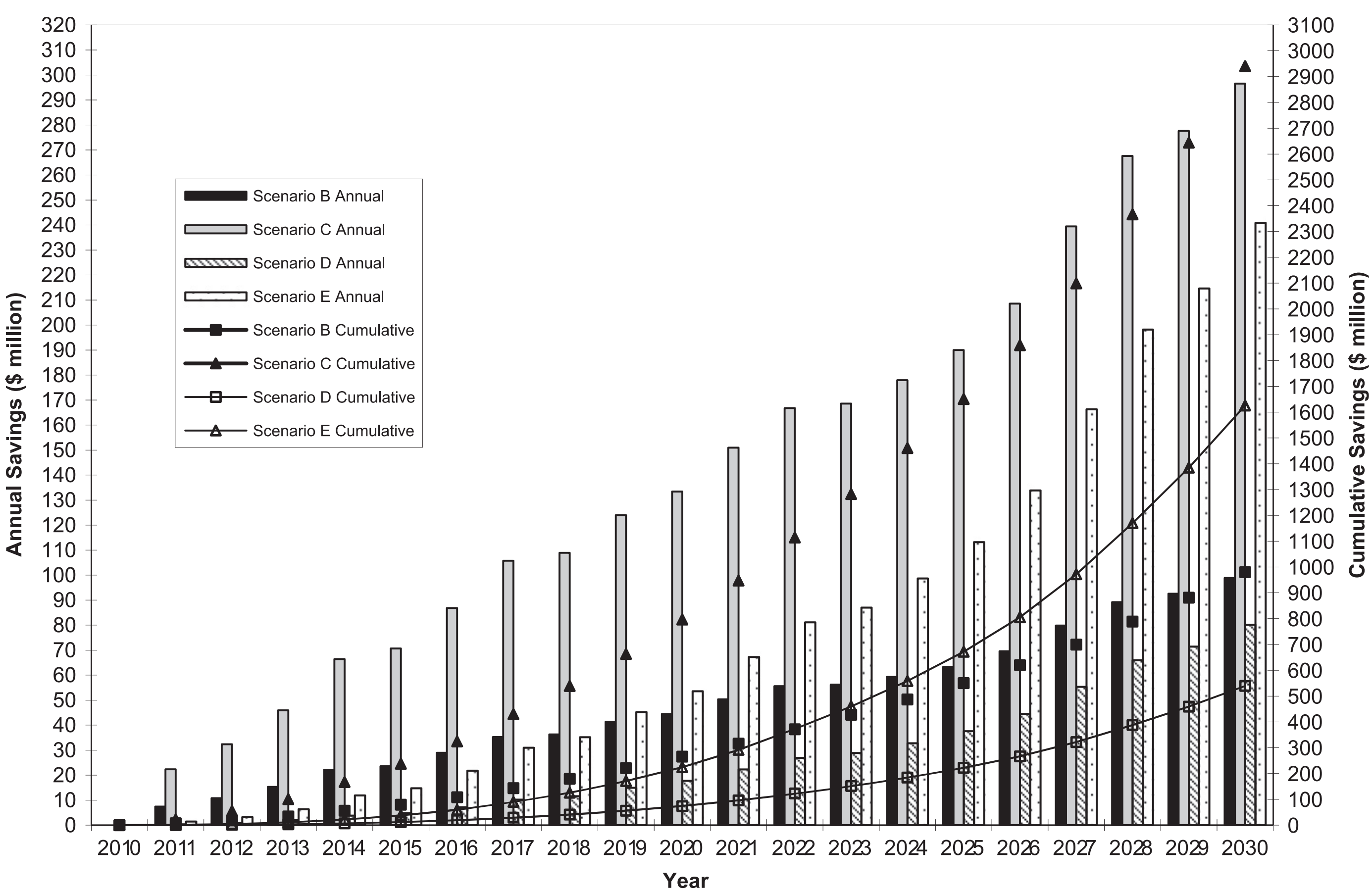

Fig. 10. Projected annual and cumulative savings in the cost of consumed energy in the transportation sector for scenarios B–E.

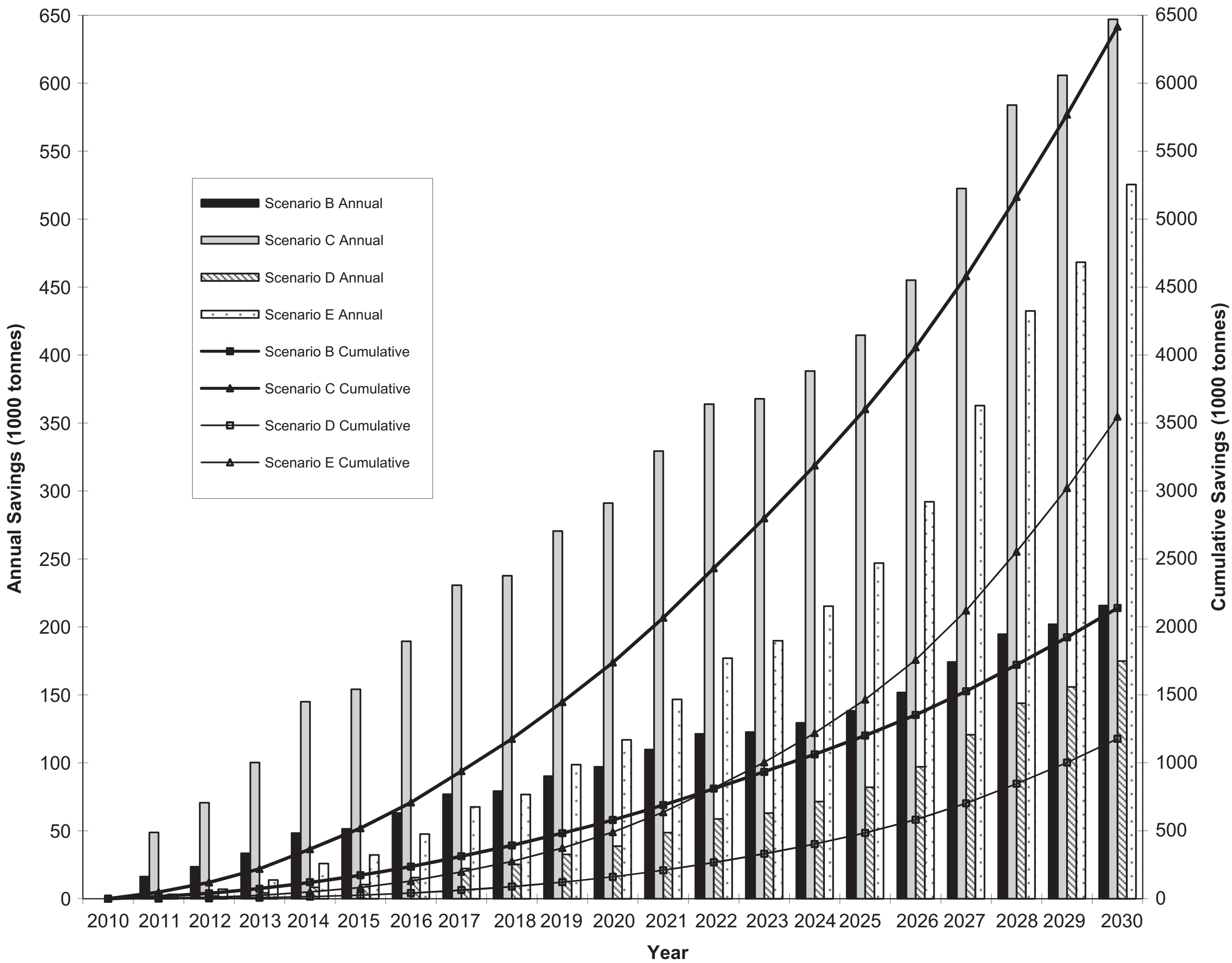

Fig. 11. Projected annual and cumulative savings in the CO_2 emissions from the transportation sector for scenarios B–E.

7. Conclusion

This study presents a comprehensive analysis of historical, current, and future situation of the Jordanian transportation sector. Jordan's transportation sector is the largest final energy consuming sector and is expected to grow faster than any other sector. It is also the most challenging in meeting sustainability goals because of its complete reliance on oil and the strong association of its growth rate with economic development. For a country that depends on imported oil that costs what is equivalent to half of its national exports, a comprehensive approach to conserve energy and slow down demand without negatively affecting economic development and welfare becomes a priority.

In order to achieve these sustainability goals, we need a robust planning and/or approaches to utilize energy sources for the future. The projections may help policy makers to plan their future energy need. In this study, a new approach has been developed to forecast Jordan's future transport energy demand that is based on two techniques: Adaptive Neuro-Fuzzy System and the double exponential smoothing method.

The energy demand values predicted by ANFIS are compared to the actual measured values in order to determine the error of ANFIS prediction system and validate the results. The average percent error of the transport energy demand values predicted by ANFIS with the (triangular) membership function is only 3%, achieving an accuracy of 97%. The results show that ANFIS is a technique that can be used efficiently to model and predict energy demand. It is believed that this approach can be applied to identify many other parameters in energy and environmentally-conscious fields.

A mathematical model was developed to evaluate the impact of introducing diesel passenger cars into the Jordanian transportation sector. The analysis demonstrated significant potential energy and environmental benefits as a result of adopting such strategy. At worst scenario, it is expected that net savings of approximately 80.2 M$ per annum, will be achieved by the year 2030, if such strategy is adopted in a gradual basis. Consequently, the associated CO_2 emission reduction will be approximately 175 thousand tons per year. The estimation methods and assumptions are clearly described in this paper so that it can be easily modified using different sets of data and assumptions to suit the studied case. Having listed the advantages of introducing diesel passenger cars into the Jordanian transportation sector that can lead to energy conservation, the implementation of such strategy is very crucial for the Jordanian sector to reach the desired energy savings. Such study can be considered as the corner stone in achieving national energy savings through implementing efficient measures. Authors believe that this analysis can be applied to

other neighboring Arab countries with similar conditions, such as Yemen, Syria, Lebanon and the Palestinian Authority.

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